11

Electric Railway Traction

Mercury Converters

A FURTHER development of the mercury rectifier is about to come into use for railway service, in the form of a frequency converter for use with alternating current. The function of rectifying alternating to direct current, of course, is absent, but the mechanical construction of converting and rectifying equipment is not greatly dissimilar. In the case under notice, a converter of 3,600 kVA. capacity will change three-phase 45 kV. 50 cycle supply into single-phase 15 kV. $16\frac{2}{3}$ cycle current for use in the overhead contact lines of the Basle-Schopfheim-Zell-Sackingen division of the German State Railway, and will replace rotary machines and batteries which have been in service since the inception of the electric service in 1913. Large scale tests of the development apparatus at the Berlin works of the makers, the A.E.G., have shown satisfactory operating characteristics, and have indicated that substantial reductions in working costs may be expected. In addition, an efficiency a good deal higher than that of rotary machines has been obtained, and it may be anticipated that mercury vapour frequency converters will have just as wide a field of application in single-phase systems as the mercury rectifier now enjoys in d.c. traction.

British Modernisation Scheme

IT is understood that the Directors of the London & North Eastern Railway have authorised the modernisation of the Tyneside electrified suburban system on a programme which has been under the consideration of the departmental officers for some time. The proposals are to accelerate and improve the services and increase the standard of comfort by the substitution of modern rolling stock for the existing cars, the first of which was put into service as long ago as 1904. The construction of 91 steel coaches is mooted, but the withdrawal of the condemned stock, which forms a goodly part of the present total of 132 vehicles will be effected gradually. Actually, the first part of the scheme has already been completed by the erection of two new remotely-controlled rotary substations at Gosforth East and Earsdon Grange, as recorded in the issue of this Supplement for April 6 last, and improved signalling layouts are now being installed in the Newcastle area. Heavier conductor rails are now being laid on certain lengths, and in conjunction with the two new substations, will appreciably reduce the voltage drop along the track.

From the passengers' point of view, the proposed accelerations and improved service are perhaps overdue, for the Tyneside lines have not been worked to anything like the present-day capacity of electrification, either in speed or frequency. The modernisation of the system will change all this and should attract more traffic. Although the population of the coastal area has been trebled within the last three decades, there has recently been a tendency for the population of Newcastle to spread west and north-west to districts which, in view of the peculiar configuration of the land, cannot be tapped by the railway. An unusual experiment was introduced in March last by the raising of the day return fare from Newcastle to the coast by 25 per cent., although the ordinary return fare and season ticket rates were slightly reduced. This is distinctly unusual, as the day trip traffic throughout the year is of large proportions, but the bus fares have also been increased recently. It is interesting to note that the open type of coach is being retained in the new construction programme as this model is considered to be the best for this particular train-service.

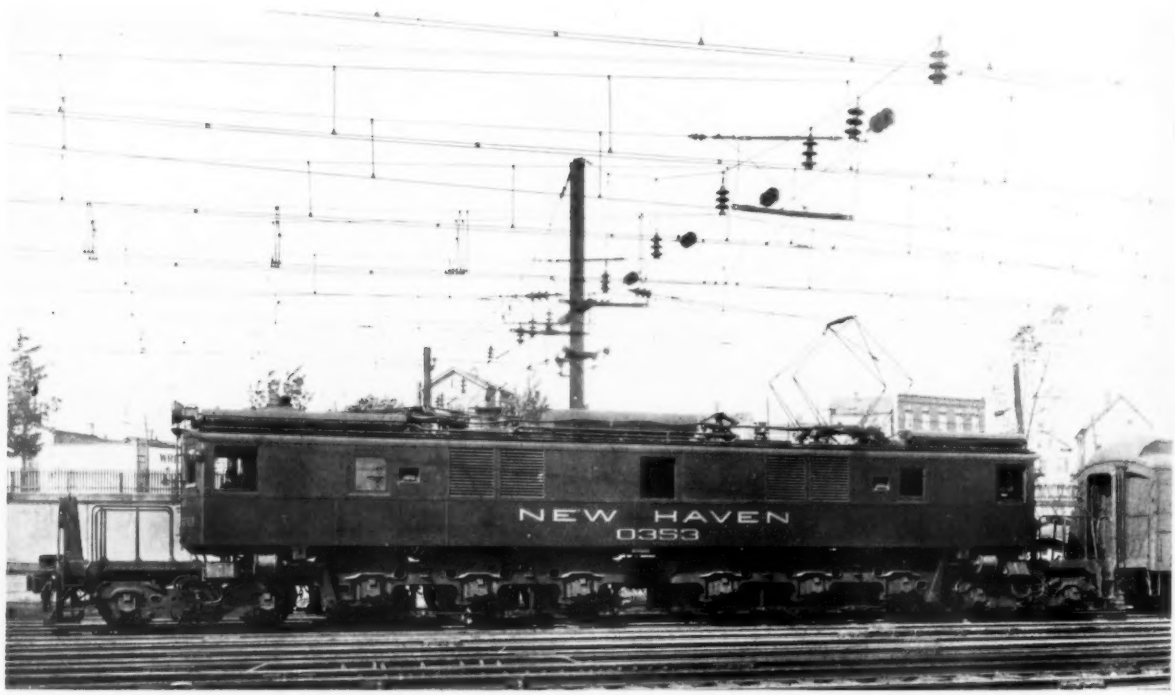
Unusual Savings by Electrification

MORE than once we have drawn attention to the difficulty of compiling with accuracy comparative figures of the economy achieved by electrification. This is due in part to the number of ancillary advantages to which definite values cannot be assigned, although the improvement in traffic operation or the saving in expenditure which they permit is undoubted. Moreover, many of these secondary advantages appear only under certain conditions, and in any event the magnitude of their importance varies with every example. A case in point is to be found on the New York, New Haven & Hartford Railroad, a description of the electrified area of which will be found elsewhere in this issue. Between New Rochelle and Bridgport, certain underline bridges were loaded up to their maximum carrying capacity, and any further increase in train weights would have necessitated expensive reinforcing or rebuilding in order to carry a heavier axle load and withstand the hammer blow of more powerful steam engines. Electrification of the line has eliminated the necessity of this work, and two or three electric locomotives with a maximum axle load of 24 tons can be coupled together and worked by one crew for the haulage of the heaviest loads, whereas a continuance of steam traction would have necessitated the use of engines with axle loads of 27 tons plus the usual unbalanced forces. Estimates of the net cost of conversion should obviously include a credit for the sum saved under this heading.

But as an instance of the vagaries of the economics of electrification may be cited the case of the Grand Central terminal in New York, used by the New York Central and New Haven Railroads. We ourselves have previously referred to the covering over of this station (made possible by smoke elimination due to electrification), as a source of added revenue to the railroad concerned, and as is stated on another page of this issue, the rentals may amount to over $3,000,000 a year. Unfortunately, all of this does not find its way into the coffers of the enterprising owners. The complete absence of smoke and the virtual elimination of noise along Park Avenue and in the vicinity of the station has made the neighbourhood exceedingly valuable as a residential and business district, and property values have advanced greatly since electrification. This reacts unfavourably on the railroad, for it has increased the tax burden appreciably.

AN UP-TO-DATE AMERICAN ELECTRIFIED SYSTEM

Intense traffic in vicinity of New York worked successfully by single-phase electric traction *



One of the latest single-phase express locomotives of the New Haven Railroad below the cross-catenary form of overhead construction used in yards and stations

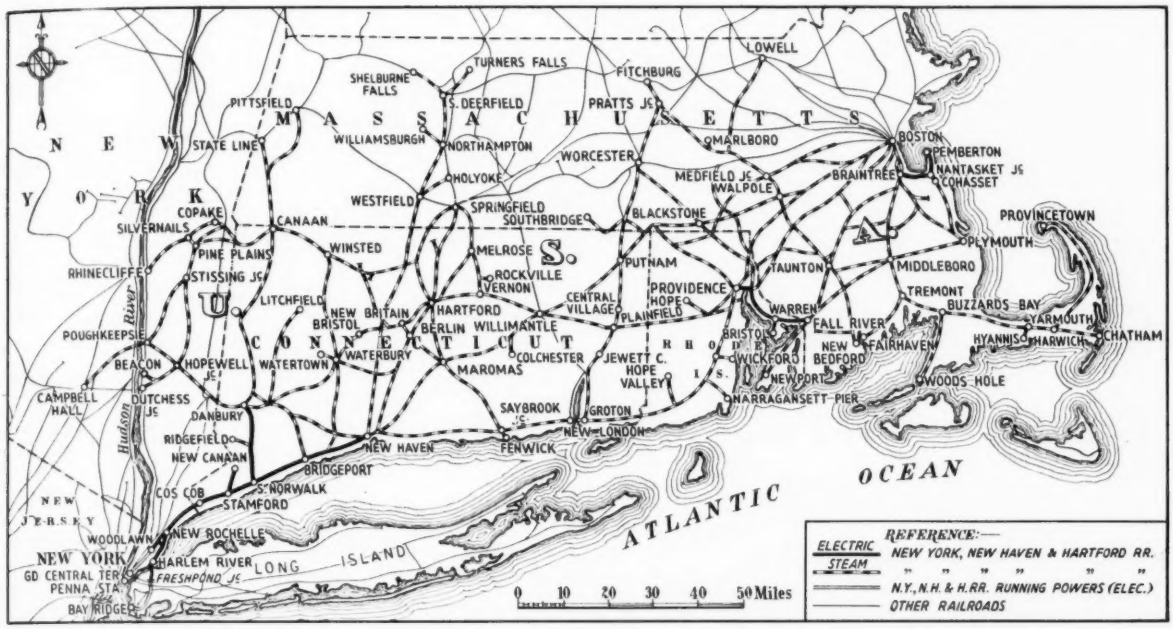
THE New York, New Haven & Hartford Railroad, colloquially known as the New Haven Railroad, occupies rather a peculiar position among the larger railroads of the U.S.A., for although the population served exclusively is approximately 3¾ per cent. of the United States total, and the gross revenue over 2 per cent. of the whole of the railroads, the mileage is only about 1 per cent. Further, the entire network of the New Haven lies within a circle of 100 miles radius, although the route mileage operated is over 2,100. This means that there are none of the long hauls found on the majority of American railways. A large suburban traffic is the main feature of the New Haven's operation, and this, together with important interurban traffic between such cities as New York and Boston, results in the passenger revenue accounting for 39-40 per cent. of the gross receipts, which average $122,000,000 per annum.

Electrification was sought early as a means of relieving the congestion caused by intense traffic over relatively short distances, and as far back as 1895, the Nantasket beach line near Boston was converted to low tension direct current operation. Another early electrified section was the Manufacturer's Railroad, at New Haven, which was acquired by the New Haven Railroad. From 1896 to 1906 a number of densely trafficked lines (now worked by railcars) in Connecticut were electrified on the low tension d.c. system, but the electrical equipment has since been removed, principally on account of legislation against third rails, but in one or two cases of short-distance interurban lines because of road competition having won much of the traffic. The only d.c. sections now remaining on the New Haven system proper are the Nantasket beach and Providence-Fall River lines, but from Woodlawn into the New York Central Railroad's Grand Central Terminal on Manhattan Island, into which the New Haven has running powers, the track is electrified at 650 volts d.c.

On the main line from New York to New Haven, 11,000-volt single-phase current is used, and in addition to pantographs for collecting power on this system, the locomotives are fitted with shoes for picking up low tension d.c. on the New York-Woodlawn division. The Harlem River branch is also electrified on the single-phase system, as is the New York, Westchester & Boston Railroad, a subsidiary company of the New Haven which runs almost alongside the main Harlem-New Haven line from Westchester Avenue, New York, to Mount Vernon, approximately seven miles of quadruple track, and then divides into two double track branches, one to New Rochelle, 2 miles, and the other to White Plains, 9½ miles.

When considering the question of the electrification from New York to New Haven, the railroad company's engineers

* Based on a paper read before the last World Power Conference by Mr. Sydney Withington, Electrical Engineer, N.Y.N.H. & H.R.R.



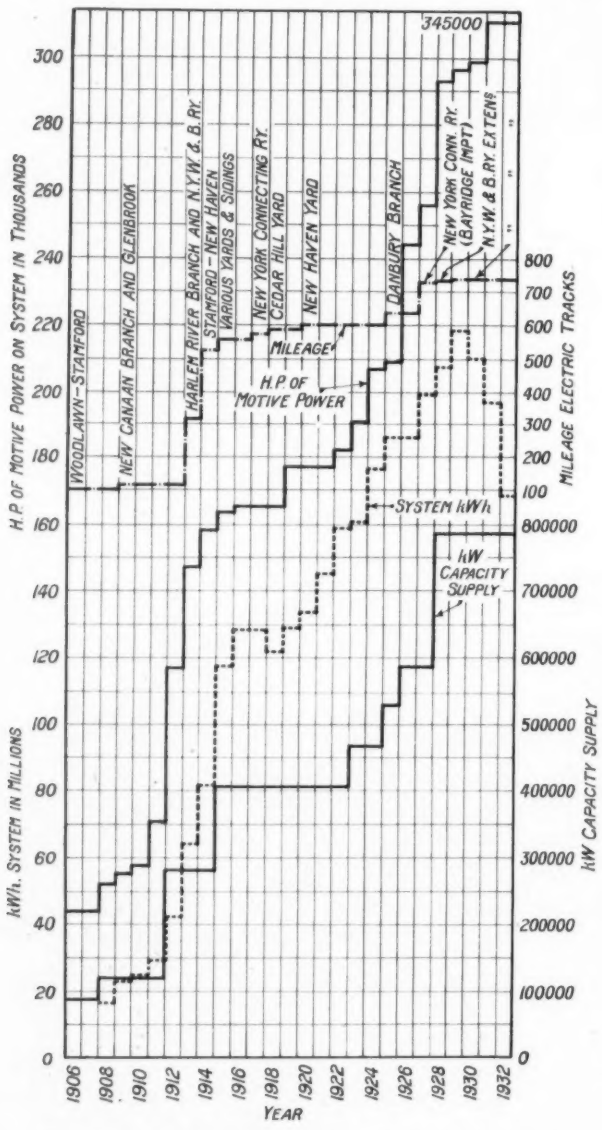
Map showing electrified lines of the New York, New Haven and Hartford Railroad

recognised the limits of low voltage d.c. for main-line work, and decided to adopt 11,000-volt 25-cycle single-phase current, although in 1907, when the first conversion was put under way, this system had never been used for a main line. It was necessary for the New Haven to produce all the power required for its own use, as no power company at that time was able to furnish current of the required characteristics. The company's power station is located at Cos Cob, between New York and New Haven, and has a single-phase output capacity of 47,000 kW. A small quantity of three-phase power is also generated, and is transmitted along the route for auxiliary purposes. Supplementary power supplies, aggregating 15,000 kW., are purchased at two points from local power companies, and there are two further connections for mutual stand-by supplies, rated at 5,000 kW. each, one with the Penn-

Standard 1-B+B-1 freight locomotive on passenger work on the South Norwalk—Danbury branch

sylvania Railroad at New York, and the other with the New Haven street tramway organisation which is a subsidiary of the railroad. For the operation of trains over the tracks of the N.Y.C. in the vicinity of New York, the New Haven purchases its d.c. from the owning company. Consideration of the accompanying graph shows that in the peak year of 1929 the current consumption rose to 218,000,000 kWh., apart from 23,000,000 kWh. used by trains in the New York Central d.c. area.

There are several different designs of overhead construction, varying with the time of installation and with the type and location of the track. All systems include a 4/0 bronze grooved contact wire with a copper wire of similar size and shape immediately above it. The cross catenary construction used in yards and stations is shown in the first of the accompanying illustrations, and another view shows a simple construction used on single lines. The main transmission line carries current at 22 kV., and the feeders and contact lines form a metallic circuit


345000
WOODLAWN–STAMFORD
NEW CANAAN BRANCH AND GLENBROOK
HARLEM RIVER BRANCH AND N.Y.W. & B. RY.
STAMFORD–NEW HAVEN
VARIOUS YARDS & SIDINGS
NEW YORK CONNECTING RY.
CEDAR HILL YARD
NEW HAVEN YARD
DANBURY BRANCH
NEW YORK CONN. RY. (BAYRIDGE IMPT.)
N.Y.W. & B. RY. EXTENS.
MILEAGE
H.P. OF MOTIVE POWER
SYSTEM kWh
kW CAPACITY SUPPLY
H.P. OF MOTIVE POWER ON SYSTEM IN THOUSANDS
kWh. SYSTEM IN MILLIONS
MILEAGE ELECTRIC TRACKS
kW CAPACITY SUPPLY
YEAR
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
0 100 200 300 400 500 600 700 800
0 100000 200000 300000 400000 500000 600000 700000 800000
1906 1908 1910 1912 1914 1916 1918 1920 1922 1924 1926 1928 1930 1932

Graph showing growth of the New Haven electrified mileage and power consumption

with the rails as neutral conductors. Balancing transformers connecting the feeder and trolley phases are placed at intervals of about four miles.

At the present time the New Haven owns 138 route and 636 track miles on the single-phase system, and details of the routes may be obtained from the table below. The New York Connecting Railroad, brought into use in 1917, has always been worked electrically. It is owned jointly by the New Haven and Pennsylvania Railroads, whose systems it connects, but has no motive power or rolling stock, traffic being operated mainly by the locomotives of the New Haven. In addition to the New York-Woodlawn line, 12 miles long and with a track mileage of 74, the New Haven also operates on low voltage d.c. the Nantasket Beach line, 5 miles long, and with a route mileage of 13, and has running powers over the single-phase line of the Pennsylvania Railroad from Freshponds junction to Bay Ridge, on Long Island.

Motive Power

Over the 800-odd electrified track miles which the New Haven operates (inclusive of running powers), passenger and goods traffic is maintained by 150 electric locomotives and 300 multiple-unit cars. In 1928, when the current consumption rose to 208,000,000 kWh., 34,000,000 passenger car miles and 67,000,000 freight car miles were handled electrically, these values representing respectively 40 and 23 per cent. of the figures for the whole system. The first passenger and freight locomotives were all of the 1-B-B-1 type, but in 1919 the 1-Co-1+1-Co-1 wheel arrangement was adopted as standard for passenger work. However, increasing train weights led to a demand for more power, and in 1931 ten 2-Co+Co-2 locomotives were built by the International General Electric Company, and their appearance is shown in the illustration at the head of this article. They have an overall length of 77 ft., a weight in working order of 180 tons, an adhesion weight of 122 tons, and a maximum speed of 70 m.p.h.

A problem of some importance on the electrified sections of the New Haven is the heating of long trains. This is accomplished by oil-fired boilers installed in the passenger locomotives, but in order to permit of the non-fitted freight locomotives handling passenger trains during holiday periods, ten trailer cars, each with an automatically-controlled boiler and fuel and water tanks, have been built. They are marshalled immediately behind the locomotive. On the new 2-Co+Co-2 passenger locomotives, 15,000 lb. of water and 3,000 lb. of oil fuel are carried for heating purposes.

An important advantage obtained by the New Haven electrification has been the saving in locomotive maintenance cost, and especially in shed expenses. Improvements in steam locomotive design and construction would have modified the maintenance costs for that form of power, but careful estimates show that even allowing for the most modern steam power the maintenance costs of electric locomotives would be 30 to 40 per cent. lower on a mileage basis.

In the use of multiple-unit trains lies one of the greatest benefits of electrification in a busy terminal, for it halves the number of movements, and at the Grand Central station in New York, operation is further facilitated by loop lines, by means of which a locomotive-hauled main line train can run right round from the arrival to the departure side without necessitating any movement on the part of the station shunting engine and without fouling the tracks of arriving and departing trains. Diagrams accompanying this article show the layout of the tracks at the Grand Central station before and after electrifica-

Tracks at the Grand Central terminal station at New York before electrification. View looking south from 49th Street. (*see plan on page* 167)

tion. The old station was at ground level, and the large yard just outside the station caused a good deal of inconvenience to city traffic. Since rebuilding, the station and tracks are completely underground, and are at two levels, thus doubling the useful track. There are now 29 track miles in the station and yard. Not only has the smoke nuisance been eliminated, but valuable building sites have become available, from which the owning railroad derives a large revenue. Two illustrations reproduced with this article show two stages of the burial, but since the second photograph was taken the New York Central building has been erected over the centre of the station.

The freehold value of the site above the station, situated in the heart of New York City, is enormous, and with the completion of the last building to be erected over the track area, the rental of the space under normal conditions would amount to about $3,000,000 a year, and this without the railroad being put to any expense in the construction of the buildings. Little of this revenue would have been available with steam traction, and it may therefore

Oak Point freight yard in New York City; there are 35 miles of track electrified in this yard

Left : Grand Central terminal area before the final buildings were erected over the tracks. The tops of passenger cars can be seen below street level. The area shown is now occupied by a 34-storey office building

Below : Park Avenue and buildings over the Grand Central terminal tracks. The New York Central Building, erected since the photograph was taken, now hides the rear of the station building in the background

be said that it is an item to be credited to electrification. If capitalised at 6 per cent., this rental would amount to a sum of **$50,000,000**, which might logically be deducted from the gross cost of electrifying the lines of the two using companies, the New York Central and the New Haven.

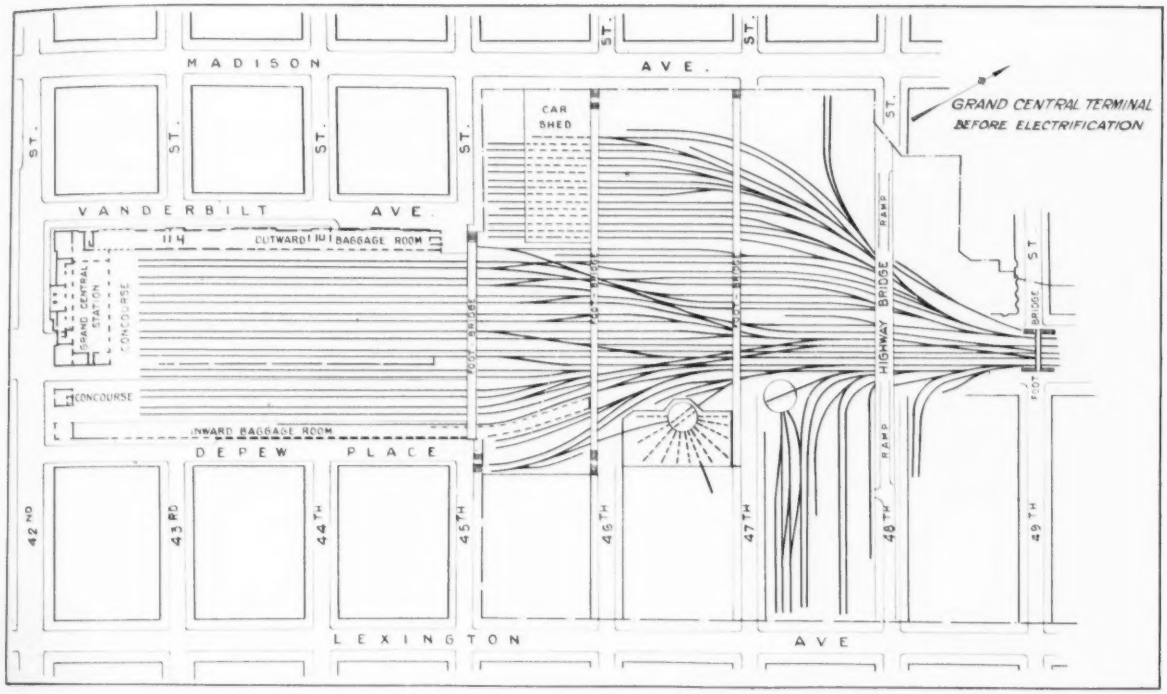
Certain other credits may be claimed for the electrification of the New Haven, such as the cost of reinforcing or rebuilding a number of underline bridges, which would have had to be strengthened if bigger steam locomotives had been built. Two or more electric locomotives coupled in multiple unit and worked by one crew can handle the heaviest trains without the maximum axle load exceeding 24 tons. The direct operating savings brought about by electrification amount to a total of about **$1,800,000**, excluding various indirect economies and advantages for which an exact figure cannot be given.

The New Haven single-phase electrification having been spread over a period of 22 years, it is difficult to get a comparative idea of the cost, in view of the many changes of great magnitude in the labour and money market since the Woodlawn-Stamford line was converted in 1907. Furthermore, a good deal of pioneer work had to be done in the early days, and this accounted for an appreciable amount of money. The power plant capital cost, like that of the distribution system, has nothing which can be credited against it, but for items such as repair shops and sheds there is from time to time a credit available by reason of facilities for steam locomotives being no longer required. For instance, on the New Haven, at Harlem River the space formerly occupied by the steam locomotive shed and sidings is now used for tracks carrying a large volume of traffic. On the other hand it was found necessary to make comprehensive changes in the signalling and communication systems in the electrified area, but these changes have made available certain operating advantages which have justified the expense apart from electrification.

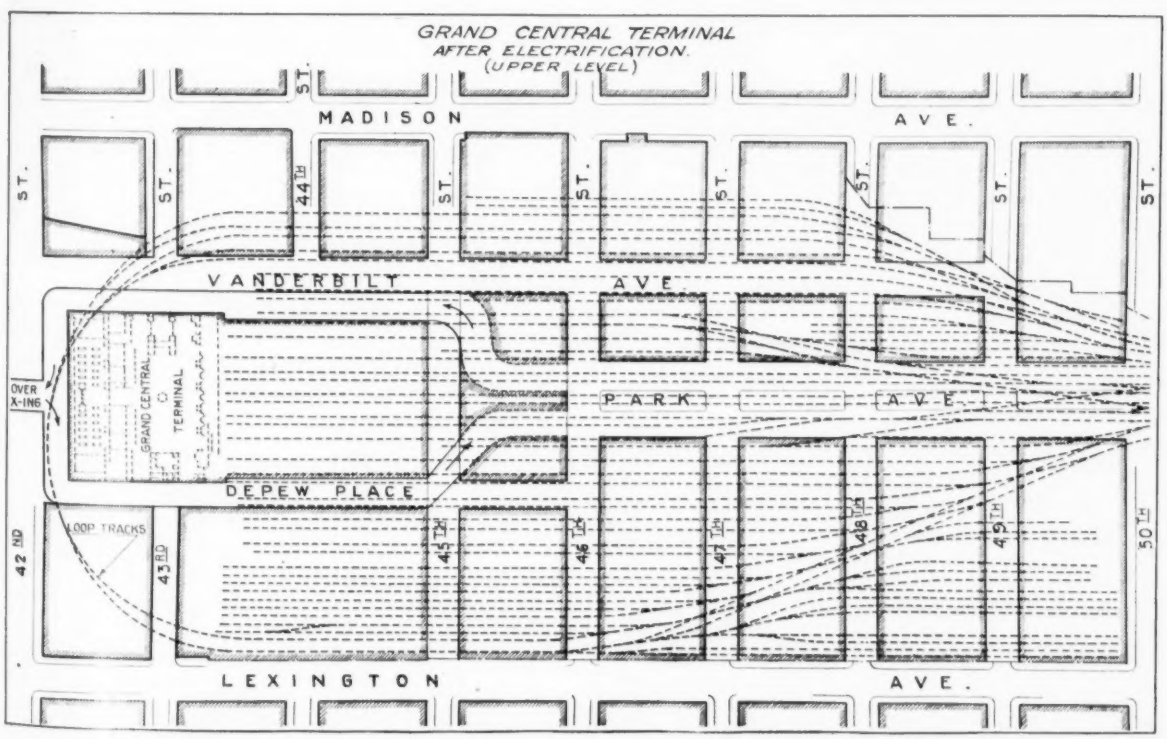
A capital expenditure of **$35,564,000** dollars must be debited against the New Haven electrification, and it is divided as follows:—

	Gross Cost
Power distribution system	$10,380,000
Power generating equipment	6,997,000
Motive power and rolling stock	15,824,000
Shops, sheds, &c.	2,353,000
Total	$35,564,000
From this may be deducted credits on account of steam locomotives released, shops, bridge strengthening, &c., amounting to	$16,864,000
Leaving a net figure chargeable to electrification of	$18,700,000

The credits deducted above do not include any allowance for additional track capacity, rentals from buildings above terminal stations, or other such sources. Assuming a combined figure of 10 per cent. for interest and depreciation, the resulting charge upon electrification is **$1,870,000**, to which must be added **$600,000** expended on the upkeep of the transmission and overhead gear. Approximately **$1,800,000** a year can be credited to fuel saving, cheaper maintenance, and fewer train crews, against which must be set electrification expenses of **$2,470,000**.



Plan showing the arrangement of the Grand Central station, New York, and the layout of the approach lines before electrification



Plan of the upper level tracks at the Grand Central station after electrification, showing the loop tracks for releasing electric locomotives and turning trains, and also the streets which now pass directly over the station

THE POSITION OF ELECTRIC TRACTION IN GERMANY

Electric operation on the German State Railway now extends over a route mileage of 1,200, of which 85 per cent. is on the single-phase system

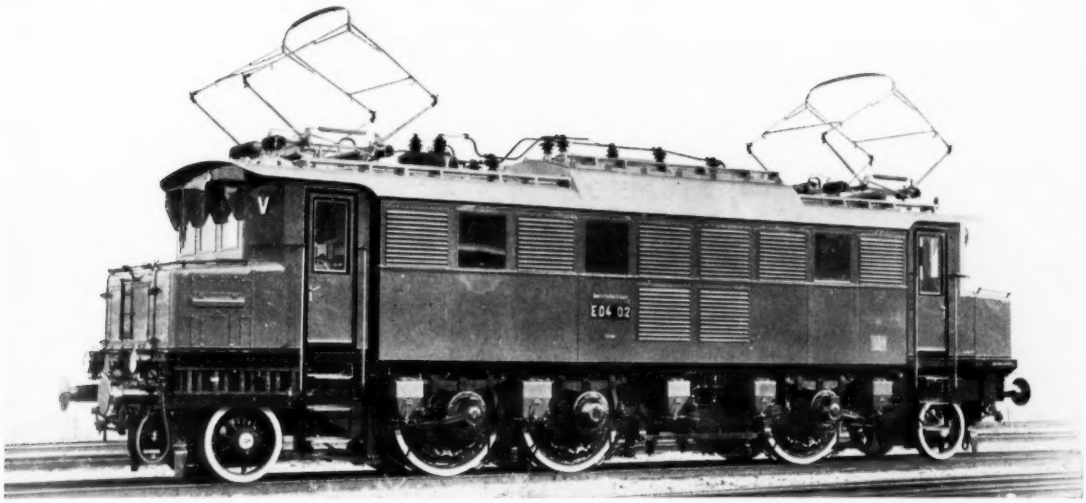
Map showing electrified lines of the German State Railway

AT the present time the German State Railway is operating six independent electric systems in addition to a few short individual tracks; these include four long-distance networks and two town and suburban railways as set forth in the attached table.

In the Central German district, electrification of the Reichsbahn began on the Dessau-Bitterfeld line in 1911, and the electric system has since been extended to the Magdeburg-Leipzig, Leipzig-Halle, Magdeburg- Rothensee, and Wahren-Engelsdorf lines, with a route mileage of 120. The Muldenstein power house of the Reichsbahn near Bitterfeld is worked on brown coal and produces single-phase current at 33,000 volts tension which, after having been transformed down to 6,000 volts, is passed on to three substations. A fourth substation will be added in the future when the Magdeburg-Köthen-Halle section, now undergoing conversion, is completed. Only minor gradients are encountered in this section. The total annual consumption of energy amounts to approximately 50,000,000 kWh.

In the Silesian area it is chiefly mountain tracks which are operated electrically. This system comprises the lines Breslau-Görlitz, the maximum gradient of which is 1 in 51; Niedersalzbrunn-Halbstadt with a 1 in 70 gradient; Ruhbank-Liebau (1 in 100); Lauban-Kohlfurt (1 in 165); Lauban-Marklissa (1 in 145); Hirschberg-Landeshut (1 in 40); and Hirschberg-Strickern with a 1 in 40 grade over a

District	Length Electrified (km.) Beginning of 1933	Length Electrified (km.) End of 1933	To be Converted	Km.	Current
1. Central Germany (Magdeburg-Leipzig-Halle)	191	191	Halle - Köthen-Magdeburg and Leipzig - Wahren	111	Single phase 15 kV., 16⅔ cycles.
2. Silesia ...	393	393	—	—	"
3. Baden ...	48	48	Höllental and Dreiseen	56	"
4. Bavaria-Wurttemberg	710	941	Augsburg-Nuremberg, Munich-Dachau, Plochingen-Tübingen	226	"
5. Hamburg town and suburbs	32	32	—	—	Single phase, 6·6 kV. 25 cycles d.c.
6. Berlin City	236	268	—	—	800 volts
7. Individual tracks	28	28	—	—	various.
Total ...	1,638	1,901	—	393	—



Single-phase express electric locomotive with individual axle drive

length of 15 miles. The single-phase current is produced at the Mittelsteine power house of the Reichsbahn, which uses inferior coal, at a potential of 32,000 volts, and is supplied to three substations after having been stepped down to 8,000 volts. In addition, three-phase current is produced by the power house for industrial purposes, the proceeds of which helps to lower the cost of railway current. The yearly production of electric energy approximates to 70,000,000 kWh.

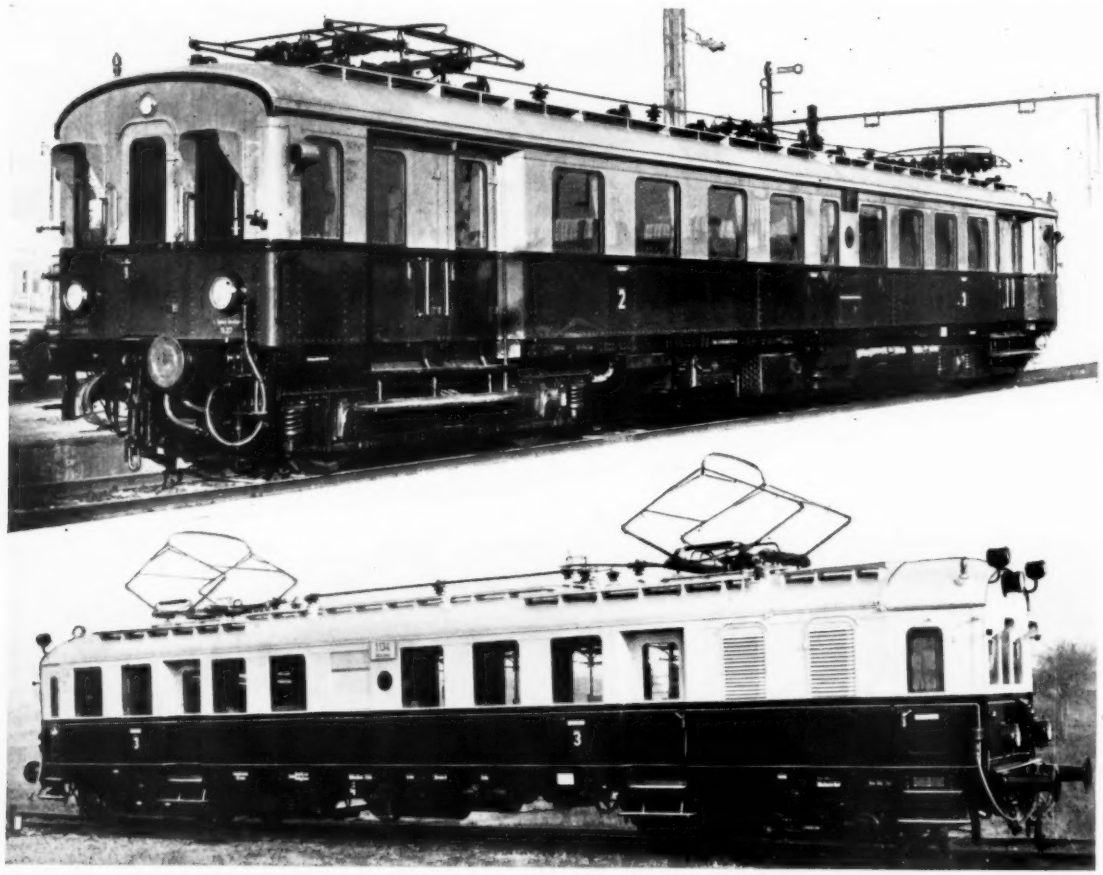
The Baden section comprises the two lines Basle-Schopfheim-Zell and Schopfheim-Säckingen which were changed over to electric operation before the war. The energy is obtained from a transformer station situated beside the Baden station in Basle, the primary three-phase current being supplied by the Augst-Wyhlen power houses on the Rhine. The first large scale converter plant of the Reichsbahn is shortly to be put up in this transformer station. The yearly energy consumption amounts to approximately 7,000,000 kWh. The electric energy for other lines in the vicinity which it is proposed to convert, (the Höllental and Dreiseen railways), will be supplied by the Baden works, hence from the national grid system of Baden, which is chiefly supported by the water power houses in the Black Forest, and by steam power stations in Baden such as the Mannheim superstation. Here for the first time the feeders will be supplied with three-phase current at 50 cycles split up into its phases, and on the locomotives it will be converted into direct-current by means of rectifiers with grid control.

By far the greatest portion of the whole German elec-

Single-phase overhead construction on the Wurttemberg section of the German State Railway

trified system is to be found in Bavaria and Wurttemberg, where important extensions were brought into operation in 1933, and further work is now in progress. Beginning with the lines first electrified, viz., Salzburg-Berchtesgaden, Garmisch Partenkirchen-Griesen, and Garmisch Partenkirchen-Mittenwald, the following important lines have been converted to electric operation, hand in hand with the extension of the Bavarian water power plant (Walchensee, middle Isar); Munich-Freilassing-Salzburg; Rosenheim-Kufstein; Munich-Regensburg; Munich-Garmisch Partenkirchen; Munich-Augsburg; Augsburg-Stuttgart. The energy is supplied by the Bavarian State water power works at Walchensee, by the plant on the middle Isar, as well as by the Saalach power house, which is the property of the Reichsbahn, and is linked up with a general industrial grid for mutual exchange of energy. The water power houses supply the current to seven substations. For the Stuttgart suburban lines to Esslingen, Kornwestheim and Unterturkheim, the electricity works of the city of Stuttgart supplies current at 6,600 volts, $16\frac{2}{3}$ cycles, produced by a special single-phase generator of 8,500 kVA. capacity in the Münster station. This generator is driven by a steam turbine at a speed of 3,000 r.p.m. Since the completion of the Augsburg-Stuttgart line last year, the important Salzburg-Munich-Stuttgart-Karlsruhe-Kehl artery, comprising a total length of 360 route miles, has been changed over to electric service to the extent of 70 per cent. or 234 miles. The Augsburg-Stuttgart section includes the Geisling bank having a gradient of 1 in 44, extending for nearly four miles. Electrically-hauled fast trains negotiate this gradient at a speed of 42 m.p.h. Steep inclines are likewise met with on a few other lines in this province. On the Freilassing-Berchtesgaden line a rise of 1 in 25 is included, and is over three miles in length. The subsidiary lines radiating from Garmisch Partenkirchen have maximum gradients of 1 in 27, but the maximum incline on the main Munich-Garmisch Partenkirchen line is only 1 in 60. The energy consumption of the Bavarian-Wurttemberg system should at present be rated at approximately 160,000,000 kWh.

The Hamburg town and suburban railway operates the line Blankenese-Altona-Hamburg-Poppenbüttel, with a length of 20 miles. Energy is drawn from the oldest steam power plant of the Reichsbahn, that in Altona, and also from the Hamburg electricity works via a grid coupling converter of 8,600 kVA., which is erected at Barmbeck, the only substation. Apart from this, the track is fed by the power house direct. The yearly energy consumption totals about 45,000,000 kWh.



Above: Brown Boveri single-phase motor coach for the Stuttgart suburban lines
Below: Motor coach built by H. Fuchs Waggonfabrik for service in the Bavarian division

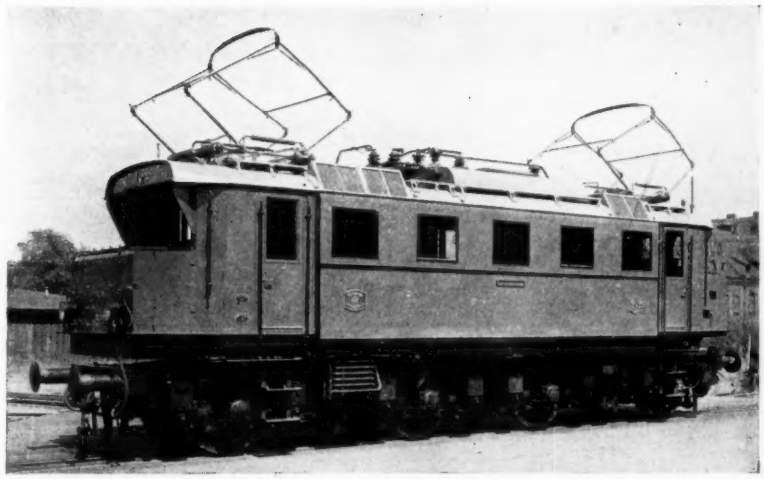
Berlin City Routes

The Berlin City Railways of the Reichsbahn have a length of 168 miles, including the Wannsee line which was opened to electric traction last year. The energy is taken in the form of three-phase current, partly from the power stations of the Berlin Electricity Works, situated in Berlin, and partly from the power stations of the Electro Works Company in the Central German brown coal area. A large number of rectifier substations are provided to convert the supply into d.c. The greater

part of these rectifier stations are automatic in operation and are remotely controlled. They are put up on the City railway at intervals of about 0·7 mile, but on outlying sections the distance is increased to 7 or 8 miles. The consumption of energy in a year is about 250,000,000 kWh.

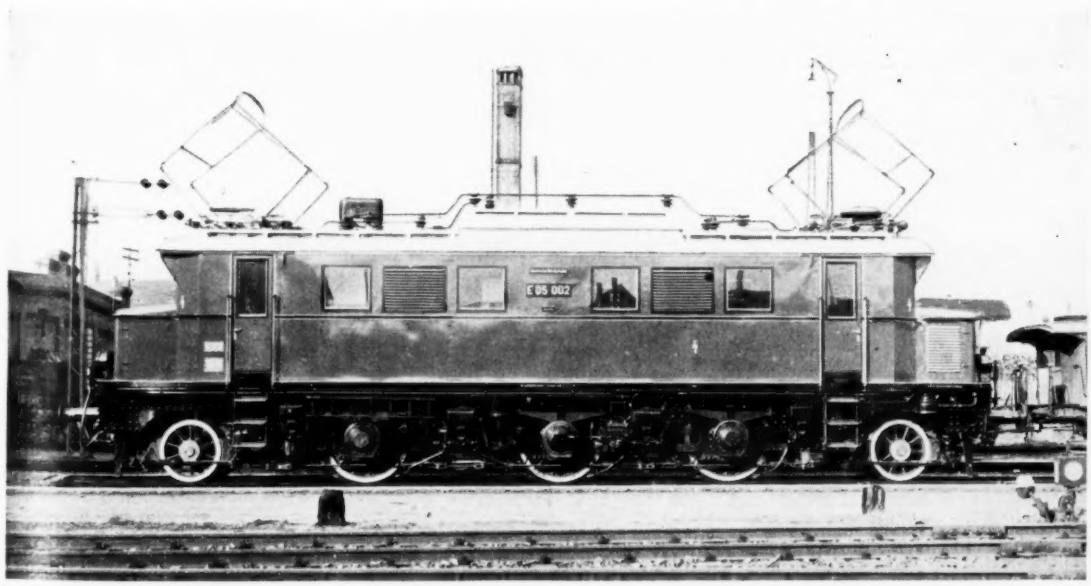
Among the individual lines detached from these six systems of the Reichsbahn may be cited the Königsee Railway, comprising the lines Berchtesgaden-Königsee and Berchtesgaden-Schellenberg, totalling 11 miles at 1,000 volts d.c., the Klingenthal-Georgental Railway, three miles long and operated by 600-volt d.c.; and the Altona Harbour Railway, which is operated with single-phase current at 3,000 volts, 25 cycles.

To operate its electrified main lines, the Reichsbahn has available 437 electric locomotives and 235 motor coaches, and a further 40 locomotives and 35 motor-coaches are in course of construction. Among the latest designs are the 10 1-Co-1 express locomotives of series E.04 with individual axle drive, described in the *Electric Railway Traction Supplement* for November 17, 1933. The maximum speed of eight of these locomotives is 68 m.p.h., while the two others are geared for a maximum speed of 81 m.p.h. One of them reached a maximum speed of 94 m.p.h. on a trial run between Munich and Stuttgart with a train load of 309 tons, as detailed in THE RAILWAY GAZETTE for July 28, 1933. A similar design is followed in the case of series E.05, which is of the 1-Co-1 type with axle-hung motors. This class was illustrated and described in the *Electric Railway Traction Supplement* for May 4 last. For passenger services with a maximum speed of 50 m.p.h., 23 Bo-Bo locomotives of Series E.44 are used. They were dealt with in the issue of this Supplement for December 15, 1933. The latest type of goods locomotive has the Co-Co wheel arrangement, and is classified as E.93. The Reichsbahn is systematically continuing trials with the three last named types of locomotive with a view to testing the suitability of nose-suspended motors for high speeds. All the new locomotive types are uniformly controlled by a standard cam gear, the intermediate stages being passed over in a continuous manner by a fine regulator of the Maffei-Schwartzkopff type.



Electric locomotive for passenger and goods trains with a maximum speed of 50 m.p.h.

Most of the new motor coaches are fitted with bogies having two driving axles, but various cars under construction have the Bo-Bo, Bo+2, Bo2+2Bo layouts. Contactor control was formerly in general use for motor-coaches, but those for the Stuttgart suburban traffic have been fitted with a control gear of the Brown-Boveri type, with rotary magnetic drive and roller contacts involving no-load switching. The motor-coaches at present in course of construction have a cam-gear control incorporated. Two recent types of motor coach are shown in accompanying illustrations. Those for the Stuttgart suburban lines have four motors of 175 kW. capacity each, run at a maximum speed of 47 m.p.h., and weigh 62 tons.



2,950 h.p. single-phase express electric locomotive with nose-suspended motors, German State Railway

MERCURY ARC RECTIFIERS—V

The construction, application and performance of steel-tank rectifiers in traction service

IT will be understood from the preceding articles in this series that there is no difference in principle between glass-bulb and steel-tank rectifiers, but the different form of enclosure in the two types results in important differences in unit capacity, constructional features and

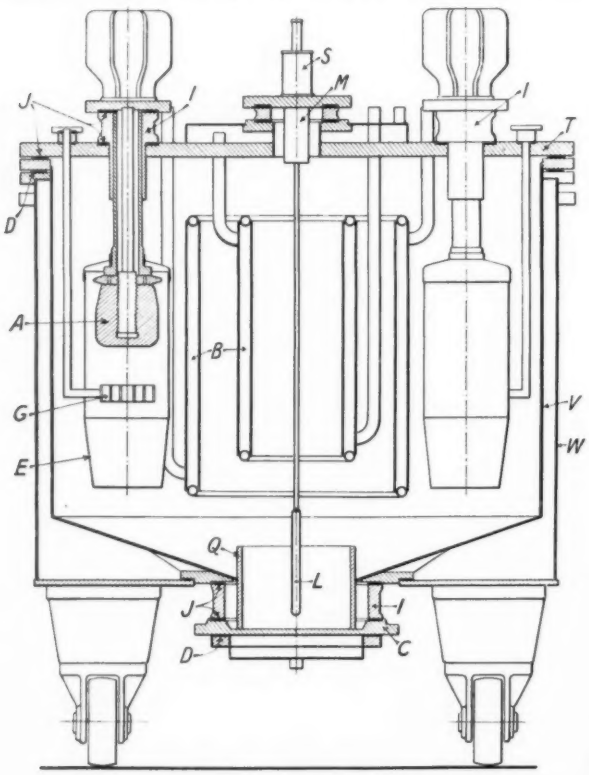


Fig. 1—Sectional view of 2,500 kW. English Electric grid-controlled rectifier

operating auxiliaries. The greater mechanical strength of steel compared with glass enables direct current outputs up to 5,000 kW., or even 8,000 kW. if required, to be obtained from a single steel-tank unit, compared with about 250 kW. maximum output from a glass-bulb unit, at 500 volts in each case. On the other hand, very high outputs are not generally required from traction substations, considerations of voltage drop imposing a limit on the length of track that can be fed from a given point and therefore on the kW. output per substation.

If, for example, a substation output of 2,500 kW. is the maximum normal output required in a particular case, this might be provided either by two banks of glass-bulb rectifiers, each bank containing, say, six or eight bulbs operating in parallel ; or it could be provided by two steel-tank rectifiers or even by a single steel-tank rectifier. There are at present in service installations corresponding closely to both of these solutions ; each has attractive features and, as matters stand, it can be said that both multiple-unit installations of glass-bulb rectifiers and single or few-unit installations of metal-clad rectifiers are capable of rendering technically and economically satisfactory service in traction work, so that the choice between the two types of equipment depends primarily on the detailed consideration of plans and tenders in individual cases.

Single-unit operation with steel-tank rectifiers is neither so risky nor so uneconomic as might appear to be the case, as would be the case with some classes of machinery. The modern steel-tank rectifier is so reliable that the risk of breakdown is almost negligible ; and the efficiency is generally within the range of 95-96 per cent. or better at all loads from $\frac{1}{4}$ to $1\frac{1}{4}$ times the rated output, so that operation of a large unit at fractional load involves no appreciable sacrifice of economy. Figures showing the reliability of the glass-bulb rectifier have already been cited, and, as regards the rival type, the B.T.H. metal-clad rectifier installed in the Old Trafford substation of the Manchester, South Junction & Altrincham Railway put in over

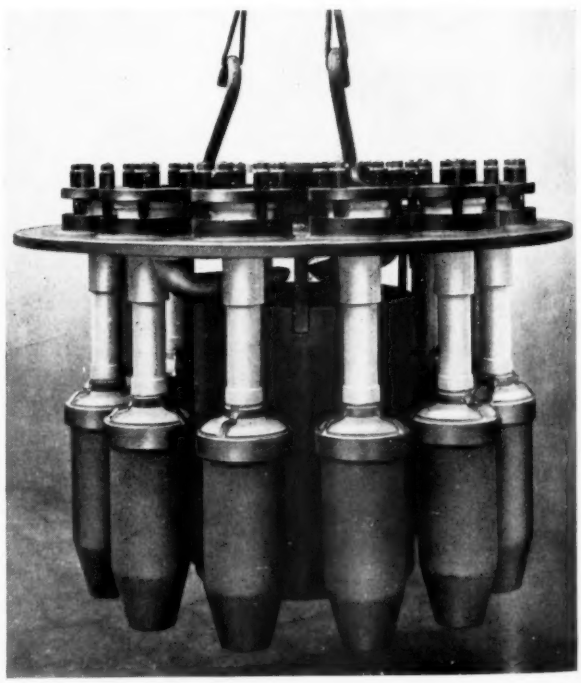


Fig. 2—Top plate of English Electric steel-tank rectifier with complete anode assembly and vapour cooler

13,500 hr. of actual operation during 1932 and 1933, and since being set to work at the inception of the line in May, 1931, has given no trouble except the furring-up of a pipe in the water-cooling system owing to the nature of the water used.

As regards overload capacity, glass-bulb and metal-clad rectifiers are on practically the same footing, their ratings being chosen accordingly. Actually there is, in each case, a certain maximum load which the rectifier could carry indefinitely, but with little or no overload

capacity, the parts vitally concerned then operating at the maximum safe temperature and having no thermal capacity to absorb any considerable amount of additional heat without being carried immediately above the safe temperature. As it is impossible in practice to operate continuously at the actual limit of safe load, the rating given to both glass-bulb and metal-clad rectifiers is usually such that, *referred to this rating*, they will carry 25 per cent. overload for 2 hr. ; 50 per cent. for 1 hr. ; 100 per cent. for 10 min. ; and 200 per cent. momentarily. The actual rating should be on the basis of the d.c. current output,

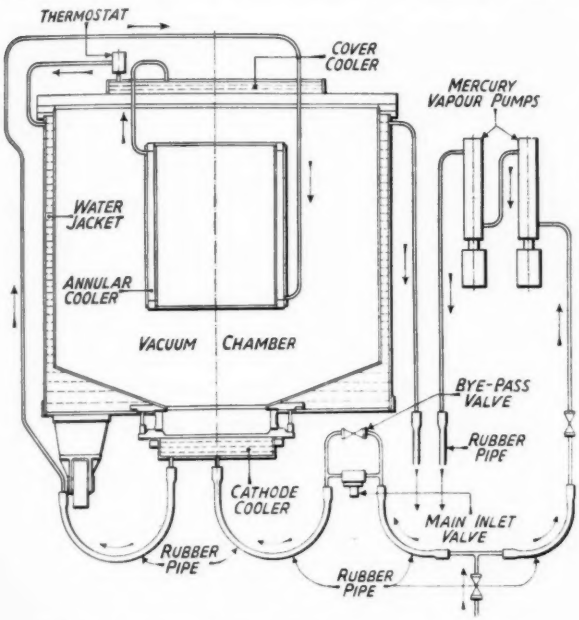


Fig. 3—Diagram of cooling water circulation system

e.g., 2,400 amp. continuously, 3,600 amp. for 1 hr., 7,200 amp. momentarily, because it is the current which determines the heating. Subject to considerations of insulation, the kW. output of a given rectifier can be increased indefinitely by raising the voltage,* but as long as the voltage is constant the kW.-output is proportional to the d.c.-amperes and the rating may be expressed in kW., *e.g.*, 1,500 kW. continuously, 2,250 kW. for 1 hr., and 4,500 kW. momentarily.

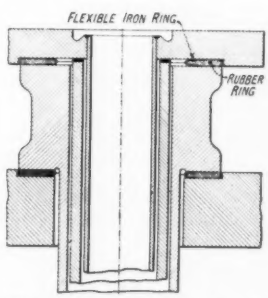
Constructional Details

The general information already given concerning the constructional features of steel-clad rectifiers may be supplemented by reference to Fig. 1, showing a section of an English Electric grid-controlled steel-tank rectifier, rated at 2,500 amp. d.c. at pressures up to 800 volts, this corresponding to 2,000 kW. output. The maintenance of high vacuum being essential, the inner chamber *V* is of welded steel construction with special jointing rings at the points such as *J* where vacuum-tightness is required, but structural considerations or the need for electrical insulation prevent the use of welding. At other joints, such as *D*, not subjected to vacuum, an ordinary gasket suffices. After removing the holding bolts, the top or anode plate *T* can be lifted away from the vacuum chamber complete with the anodes and vapour cooler, as shown in Fig. 2.

An outer cylindrical tank *W*, Fig. 1, of boiler plate, constitutes the main structural member of the rectifier and forms an annular water space round the vacuum chamber for cooling purposes. A water-cooled steel pan *C* containing the mercury cathode is insulated from the vacuum chamber by an insulator *I*, a similar insulator being used to insulate the stem of each anode from the cover plate. The general arrangement of the complete cooling system is shown in Fig. 3. Clean water has a very high electrical resistance, but in order to prevent short-circuiting through the pipes conveying it, lengths of rubber hose are inserted, as shown in the drawing. The purpose of the concentric annular coolers *B*, Fig. 1, is to assist the definite circulation and effective condensation of mercury vapour in the space within the ring of anodes.

The ignition and excitation anode *L* is carried by a rod with a mercury float in the chamber *M*, and dipped electro-magnetically by a solenoid *S* when the arc is to be struck. The form of the vacuum chamber is such as to return condensed mercury automatically to the cathode pool. The insulation of the cathode pan eliminates the tendency which would otherwise exist for the arc to wander on to the walls of the vacuum chamber; and the provision of a protruding quartz cylinder *Q* localises the cathode spot on the central portion of the mercury pool. Condensed mercury returns to the outer, annular portion of the pool which is baffled to prevent a cathode spot forming thereon. Normally, there is no deterioration of any kind inside a mercury rectifier, but some form of arrestor may be provided in the return path of the condensed mercury to form a " trash rack " holding any traces of oxide or other foreign material.

The arrangement of the anodes and grids is very important from the standpoint of reliable operation and freedom from backfire. The anode tip *A* may be of iron or



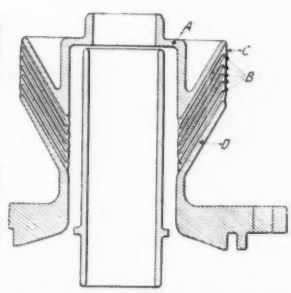


Fig. 4 (left)—Diagram of iron and rubber sealing rings
Fig. 5 (right)—Section of vitreous anode seal

graphite, a special grade of graphite being used in the English Electric rectifiers (Fig. 1), which is not liable to cause condensation of mercury on its surface and does not require to be preheated when putting the rectifier in service. The graphite block is screwed on to a solid iron support welded to a steel tube which passes through the insulator in the cover and terminates in a flange to which the anode radiator and cable terminal are bolted. The anode radiator has fins as shown and contains oil which passes down the tubular portion of the anode stem, thus providing effective cooling. The anode shank is protected by insulation down to the tip, and each anode is shrouded by an iron sheath *E*, in order to prevent condensed mercury coming into contact with the anode. The sheath *E* is open only at the bottom, so that the arc between any anode and the cathode must necessarily pass through the corresponding grid *G*, from which an electrical connection is taken to a terminal on the cover for control purposes. Further reference to grids and their uses is made later.

The size of the anodes varies considerably, but they

* Provision is made in the glass-bulb rectifier substations of the Liverpool-Southport and Manchester-Bury lines of the L.M.S.R. for 25 per cent. increase in d.c. voltage, with an equal increase in kW. output for the same d.c. current.

are generally from 4 to 6 in. in diameter, with arc guides from 6 to 10 in. in diameter. The length of the arc depends on the size and voltage of the unit and may be 30, 40 or 50 in. The area of the cathode pool in a 4,000 amp. rectifier exceeds 300 sq. in., whence will be realised the desirability of restricting the wandering of the cathode spot in order that the length of arc, and therefore the arc drop and the output voltage, may be as steady as possible. In single-unit 3,000 kW., 625-volt steel-tank rectifiers developed in the United States for traction and similar service, mercury is evaporated from the cathode at the rate of about 14 lb. per min. at the maximum overload rating of three times full-load current.

The maintenance of satisfactory vacuum in a steel-tank rectifier obviously depends essentially, though not solely, on the airtightness of the demountable joints—as distinct from the permanently welded joints in the walls of the vacuum chamber. Fig. 4, relating to English Electric practice, shows a vacuum seal of the composite ring type, a ring of rubber being combined with a flexible iron V-ring on the vacuum side. A new form of anode seal developed by the General Electric Company, shown diagrammatically in Fig. 5, consists of a number of thin mild steel rings *B*, of truncated conical form, each enamelled with a special glass *C*. After assembly of these cones and the top and bottom members *A*, *D*, the whole is fused solid in an electric furnace. A high degree of electrical insulation between *A* and *D* is provided by the layers of glass, and the complete construction is mechanically strong, perfectly vacuum-tight, and can be bolted down to the top plate of the rectifier. This device, in conjunction with an improved metal to metal joint, enables rubber and mercury seals to be eliminated, and water-cooling of the anode radiators is unnecessary.

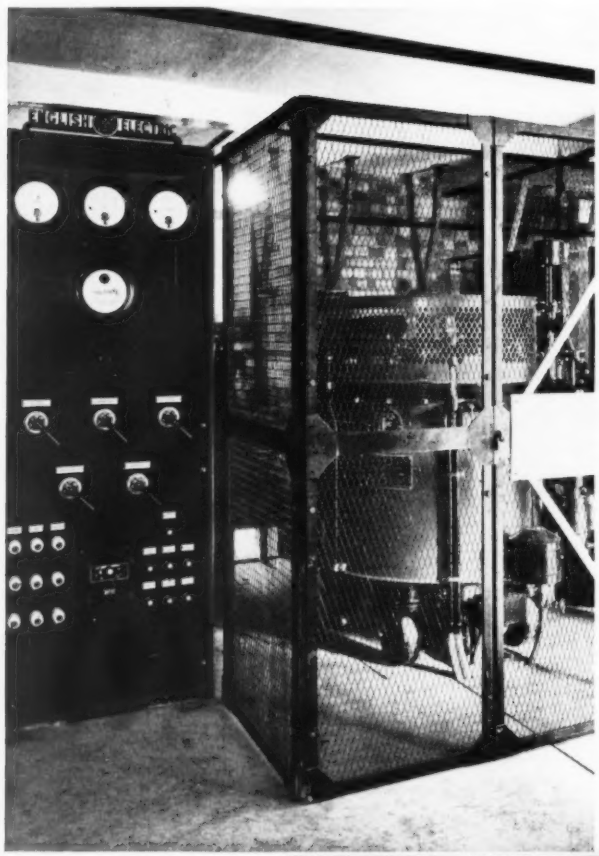


Fig. 6 (above) — English Electric steel-tank rectifier of 550 kW. capacity at 500 volts

Typical Installations

The simplicity and compactness of a steel-tank rectifier and its control panel are evident from Fig. 6, showing an English Electric 6-phase unit, fed at 6,600 volts, 3-phase, 50-cycles on the e.h.t. side and capable of a continuous output of 1,100 amp. at 500 volts, *i.e.*, 550 kW., on the d.c. side. The rectifier is enclosed in a padlocked cubicle of expanded metal work to prevent unauthorised access; and the equipment of the adjoining control panel includes output ammeter and voltmeter; vacuum gauge indicating to $\frac{1}{1000}$ mm. mercury column; and switches for the exhausting, cooling and baking-out equipment.

A much larger unit and one of the latest to be built is illustrated by Fig. 7, which shows a 2,500 kW. Bruce

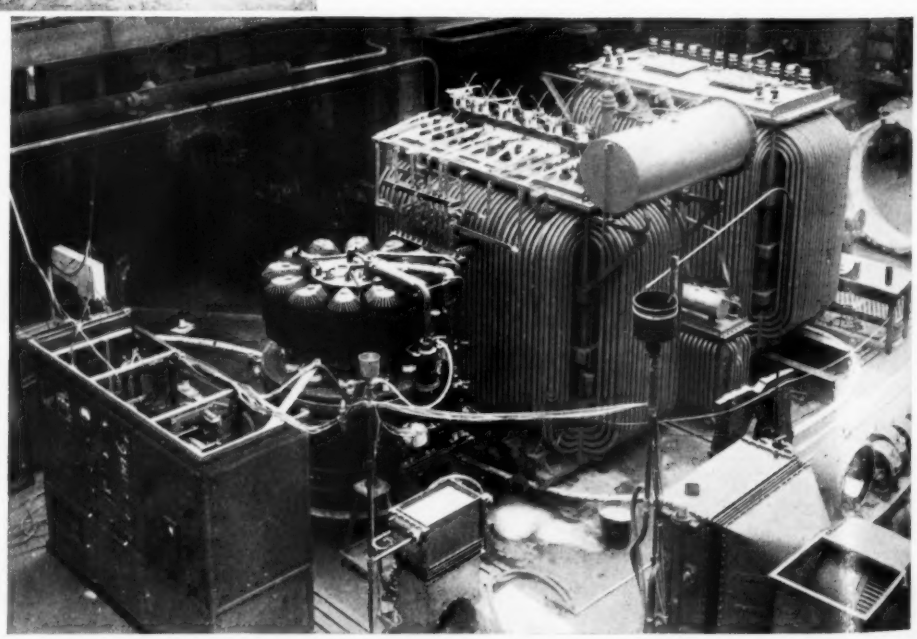


Fig. 7 (right)—One of the 23 Bruce Peebles 2,500 kW. steel-tank rectifiers for the new Southern Railway extensions on test at the works of the makers

Peebles steel-tank rectifier under test. This particular unit is one of twenty-three similar units—equivalent to a total capacity of nearly 80,000 h.p.—which are being supplied to the Southern Railway Company in connection with the Eastbourne-Lewes-Hastings and the Sevenoaks electrification schemes. Each set of equipment consists of a rectifier, main transformer, switchgear and all accessories and auxiliary plant; and the whole constitutes the largest rectifier order yet placed in Great Britain. The photograph shows one of the rectifiers complete with main and auxiliary transformers, control board and re-coolers. The transformer at the right of the picture was used to raise the 6,600 volts, 3-phase, 50-cycle works supply to 33,000 volts, which is the normal supply voltage for the main transformer operating in conjunction with the rectifier. It may be noted that the equipment was tested at 2,500 kW. for 12 hr. and at overloads from 3,000 kW. to 8,000 kW. for shorter periods; also, that short-circuit tests were carried out successfully at no-load and full-load.

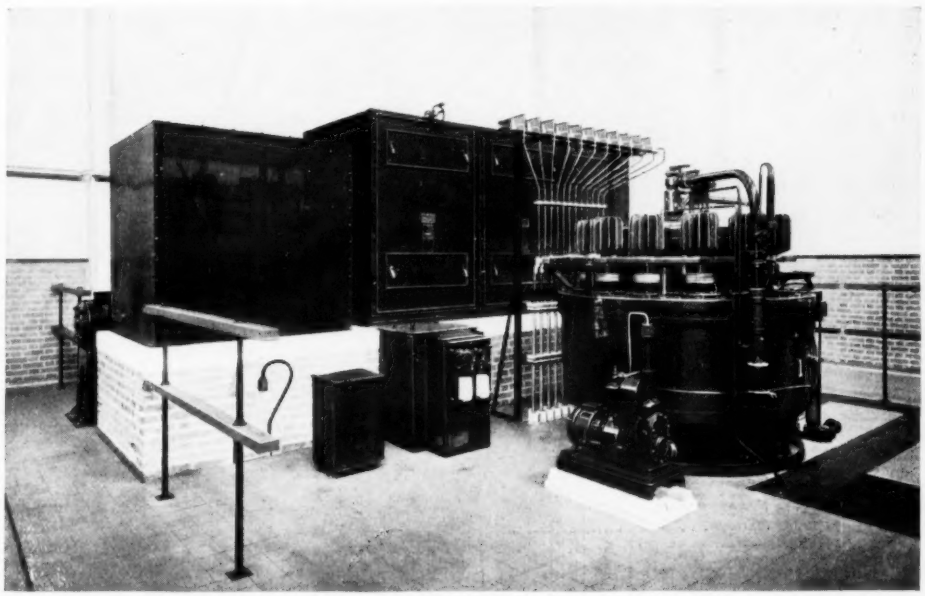


Fig. 8—One of the three 1,500 kW. G.E.C. steel-tank rectifiers in Chiswick Park substation, London Passenger Transport Board

Another important installation of steel-tank rectifiers operates in connection with the Hammersmith to Hounslow and South Harrow extensions of the London Passenger Transport Board's Piccadilly line. Extra high tension supply at 11,000 volts, 3-phase, 33⅓ cycles is fed to five substations containing a total of thirteen 1,500 kW., 630-volt rectifiers, space being provided for the substitution of 2,500 kW. rectifier units as required. In each substation the rectifiers are installed on the ground floor with their air-blast transformers, re-coolers for the rectifier cooling water, smoothing chokes, control boards, oil circuit-breaker cubicles, isolating switches and d.c. busbars; while a gallery running the length of the substation carries the d.c. high-speed circuit breakers, negative contactors, operating transformers and e.h.t. busbar chambers. Fig. 8 shows one of the three General Electric Company's 1,500 kW. equipments in Chiswick Park substation. All the substations on this extension are normally unattended and four of them are remote controlled from a room in the Alperton distribution station through pilot wire circuits which provide for all the requisite controls.

Maintenance and Measurement of Vacuum

Where glass-bulb rectifiers are concerned, the problem of maintaining the vacuum does not arise. The bulbs are sent out by the makers suitably evacuated and ready for service; and, barring accidents, they remain ready for use continuously or intermittently, with idle periods of any duration, for years on end. If re-evacuation of a glass-bulb ultimately becomes necessary it is a job for the makers; the user's equipment includes neither vacuum pump nor vacuum gauge. Where steel tanks are concerned, however, there is always the possibility of tiny leaks through the relatively large mechanical joints; also, there is more or less emission of occluded gases from the internal parts of the rectifier when they become hot. There is no difficulty in removing such gases as may be present from either of these causes by means of vacuum pumps, but such pumps and vacuum gauges to measure the actual pressure in the rectifying chamber form part of the standard equipment of steel-tank rectifiers at present in service. Recent researches in Germany indicate that there is a diffusion of hydrogen from the cooling water through the iron walls of the vacuum chamber; and that, if a hydrogen-free cooling liquid be employed and packed joints be avoided by welding, there is no need to provide a vacuum pump. Special fused metal and glass joints are used at the anodes and cathode. It is too early yet to express any opinion as to the effect of these researches on future design, but an experimental 640 amp. metal-clad rectifier cooled by liquid free from hydrogen ions is said to have operated for many months without a vacuum pump and with a gradually hardening* vacuum.

It is essential that the pressure in a mercury rectifier should be below 0·01 mm. of mercury column, and the usual working pressure is 0·001 mm. Instead of quoting such very small heads of mercury, the pressure is often expressed in microns, one micron corresponding to a mercury head of one-thousandth of a millimetre. Two-stage pumping is required to establish such high vacua. The two pumps are connected in series, an oil-filled motor-driven box pump producing a vacuum corresponding to a few millimetres head of mercury, while a mercury vapour diffusion pump establishes a high vacuum in the rectifier by removing traces of gas and delivering them to

* Owing to possible confusion between "high" vacuum (which corresponds to a low absolute pressure) and "low" vacuum (which means a higher absolute pressure), the term "hard" is often used to signify a high, good or nearly complete vacuum, while "soft" is applied to a vacuum which is poor or has deteriorated by leakage or otherwise.

the mechanical roughing pump. The mercury diffusion pump operates on the principle of the steam ejector. Mercury is boiled by a small electric heater of about one kW. capacity, and the vapour passes through one or more jets which extract gases from the rectifier ; the mercury vapour is then condensed and returned to the boiler, while the gases are delivered into a reservoir whence they are withdrawn by the roughing pump, compressed and discharged to the atmosphere. The diffusion pump operates continuously, but the rotary pump generally runs for only 10-15 min. per 24 hr., this machine being started automatically whenever the gas pressure in the interstage receiver reaches a predetermined value.

A suitable non-return valve is required between the roughing pump and the mercury pump to prevent access of atmospheric pressure to the latter when the rotary pump is shut down. A barometric seal can be used for this purpose consisting, as shown diagrammatically in Fig. 9, of a 30-in. barometer tube with an enclosed well. The high vacuum pump is connected to the top of the barometer tube and is thus kept under vacuum even when there is full atmospheric pressure on the mercury in the well-chamber *W*, due to the rotary pump being stopped. On the other hand, when the rotary pump is started, the pressure in the well-chamber is reduced, the mercury descends in the sealing tube, and the roughing pump can draw gas from the interstage receiver. The chamber *T* with its standpipe *S* forms a trap preventing oil from reaching the barometric seal.

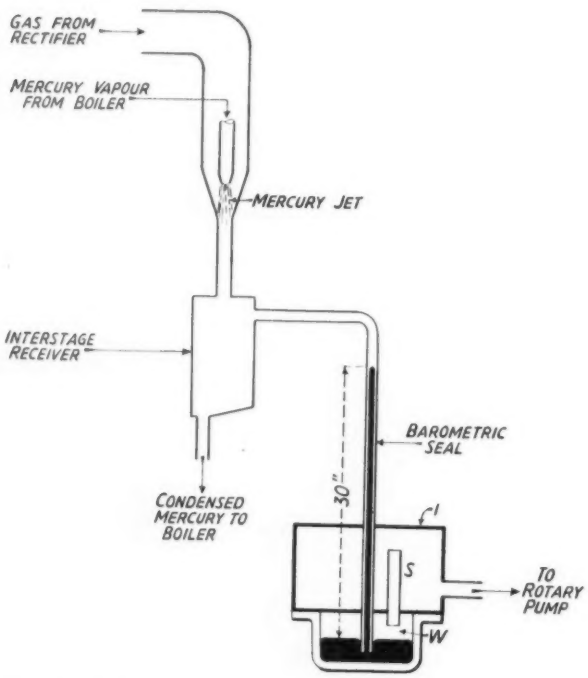


Fig. 9—Diagram of two-stage pumping with barometric seal

The accurate measurement of the low pressure in a mercury rectifier requires equipment differing materially from ordinary types of pressure gauges. A McLeod gauge is often fitted for control purposes, the principle of this apparatus being that a sample of the vacuum is compressed up to atmospheric pressure by means of a movable mercury column, the requisite movement of which is a measure of the initial pressure of the gas in the vacuum space. This gauge has to be adjusted manually for each reading and is unsuitable for continuous indications. For direct readings by a pointer and scale calibrated in microns, and for use in conjunction with automatic control, the Pirani vacuum gauge developed in the Research laboratories of the G.E.C. offers important advantages. The principle employed is that two metal filaments connected to a constant voltage derived from an auxiliary transformer and metal rectifier are enclosed in separate glass vessels, one evacuated and sealed and the other open to the vacuum chamber of the mercury rectifier. According as the rectifier vacuum is higher or lower, compared with that in the sealed bulb, the temperature and therefore the resistance of the filament in the measuring bulb is higher or lower than that of the second filament. The two filaments form two of the arms of a Wheatstone bridge, the indicating instrument of which is calibrated to read directly the pressure in the rectifier chamber.

Cooling

The general arrangement of a typical cooling system for a steel-tank rectifier has been explained in connection with Fig. 3. The purpose of the cooling water is to remove the heat developed by the electrical losses in the rectifier, including the heat developed at the terminal surfaces of the arc on the anodes and cathode and in the body of the arc itself. If there is a pressure drop of 25 volts between the anode and cathode, and the d.c. output is 1,000 amp., the power converted to heat is 25 volts × 1,000 amp. = 25 kW., corresponding to 25 × 3,412 = 85,300 B.Th.U. per hr. This quantity of heat would raise the temperature of 142 gallons of water per hr. from 60 deg. to 120 deg. F. The quantity of cooling water actually required varies with circumstances, but it should be noted: (1) That the quantity is always relatively small, corresponding to the high efficiency of the mercury rectifiers ; (2) the amount of cooling water increases nearly in proportion to the current rating of the rectifier, the internal voltage drop being nearly constant.

A running supply of water is sometimes used for cooling steel-tank rectifiers, but if water is expensive or ever likely to be scarce, a closed circulating system should be used, with a natural, fan-ventilated, or water-cooled (heat exchanger) recooler. In some instances, the heat dissipated by the recooler serves a useful purpose in keeping the substation free from condensation or sweating. If the normal water supply is of low electrical resistance, corrosive, or scale-forming, a closed-circuit cooling system must be installed using clean water prepared by distillation if not otherwise available. A separate closed-circuit cooling system for each rectifier is good practice ; and a thermostat is generally provided to vary the rate of water circulation according to the load on the rectifier.

The converse of the problem of cooling the rectifier during normal operation is that of warming idle rectifiers during cold weather. Trouble was often experienced with the early steel-tank rectifiers when starting from cold and, though this has been eliminated in modern rectifiers which can be switched on to heavy loads at ordinary room temperature, internal tank heaters are sometimes installed as a precautionary measure in rectifiers which are to be used in unheated substations. As a case in point, tank heaters set to operate automatically at 5 deg. C. (41 deg. F.) are installed in the 1,500 kW. G.E.C. steel-tank rectifiers of the London Passenger Transport Board's western extension previously mentioned. No provision is made for heating the substations themselves, otherwise than by the losses in the equipment installed, and a further reason for the use of internal tank heaters lies in the fact that the a.c. supply is at 33⅓ cycles, at which frequency cold-starting difficulties are much more pronounced than at 50 cycles per sec.

FAST RAILCARS IN SWITZERLAND

With a view to speeding up certain services on the electrified lines several light weight high-speed electric railcars have been ordered by the Swiss Federal Railways, and will have a maximum speed of 125 km.p.h. (78 m.p.h.) compared with the service maximum of 90 to 100 km.p.h. (56 to 62 m.p.h.) of the present electric locomotives. The layout of these cars is shown in the accompanying diagram. The order for the electrical equipment has been divided between Brown Boveri, Oerlikon, and Secheron, and the mechanical portions are being built by the Swiss Locomotive Company. The new railcars will be first introduced on sections of line where the running costs of locomotive-hauled trains are more than the receipts, and in this way it is hoped to reduce the expenditure, apart from the increase in traffic which is expected in view of the higher speed.

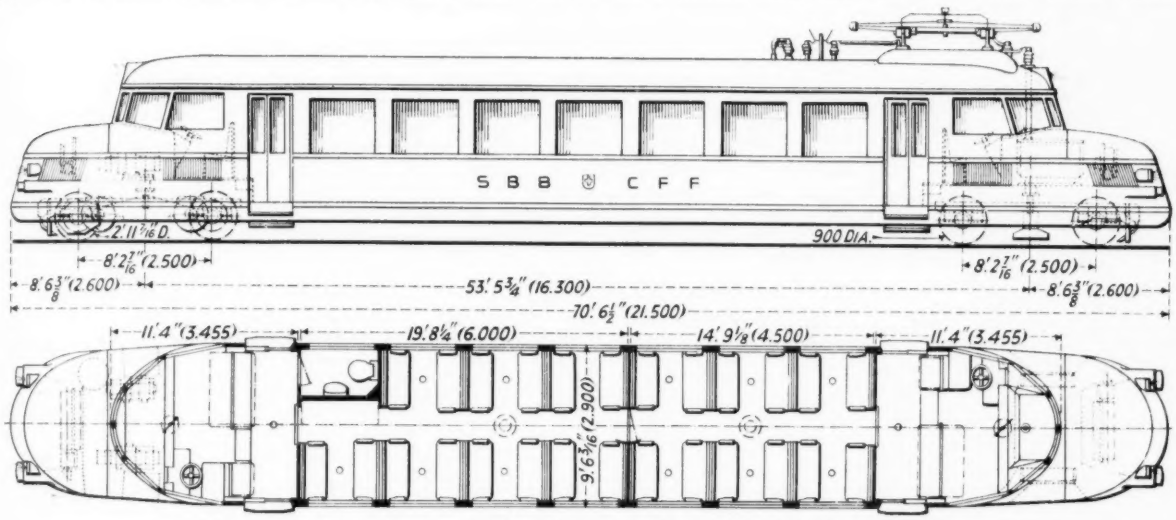


Diagram of new express electric railcars for the Swiss Federal Railways

The new railcars will be of the double-bogie type with a semi-streamlined contour, and two 130 kW. nose-suspended motors on one bogie. Single-phase current at a tension of 15,000 volts will be collected from the overhead line by a single pantograph, and passed through a 220 kVA. oil-cooled transformer before being led to the traction motors. The control is to be a combination of the electro-pneumatic and mechanical-pneumatic systems, but the air compressor, auxiliary transformer and battery will be of standard design. Four types of braking will be used, electric braking on the driving bogie through the two motors; a magnetic rail brake between the wheels of the carrying bogie; an air brake on the driving bogie; and a hand brake in each driving cabin applying the blocks on the adjacent bogie only. The magnetic rail brake on the carrying bogie is to be applied automatically when the electric braking on the driving bogie is brought into action.

An extensive use will be made of light metals and alloy steels in the construction of the underframe and body. The bogie centres will have a pivoting function only, as the weight of the superstructure is to be carried directly on laminated springs secured to the bogie frame. The body will be divided into smoking and non-smoking saloons entered from end doors, and will be fitted with lavatory accommodation. Seating accommodation for 52 passengers will be provided in the saloons, and 18 folding seats are fitted in the end gangways for use in rush hours. The seats are to be of the non-reversible type built up on tubular steel frames. Ventilation and heating will be effected by blowing air through the car and inserting an electric heater in the circuit during cold weather. The driver's controls and auxiliary equipment in each cab are duplicate.

It is expected that these railcars will tare 31·5 tonnes, made up of 11·5 tonnes of electrical equipment and 20·5 tonnes for the mechanical portion. They will be used on services giving daily mileages up to 700 km. (435 miles). Leading dimensions will be found on the accompanying diagram.

French Electrification Scheme.—Electrification of the Paris-Le Mans main line of the State Railways has been decided upon. This line runs westward from the Montparnasse terminus through Versailles and Chartres to Le Mans, 131 miles. The announcement of this decision was made by M. Raoul Dautry, General Manager of the State Railways, in a press interview last week. This electrification will of course be carried out on the 1,500 volt d.c. system and the overhead catenary suspension similar to that in use on the P.O.-Midi lines will be employed. The supply of electric power will be derived from the Paris district and will be supplemented by feeders connected with the hydro-electric works of the Massif Central, which already furnish power to the Paris-Orleans and the Paris area.

Indian Electrification Extension.—It is understood that the administration of the Indian State Railways (Great Indian Peninsula Railway) is considering proposals for the extension in the near future of the 1,500-volt direct current main line electrification system from Igatpuri to Bhusaval. If the scheme for the supply of electrical energy from the Pench river, near Nagpur, materialises, there is a possibility that the electrification will be continued to Nagpur.

The Cost Factor in Roller Bearings

THE factor of initial cost is the chief problem which seems to cause railway engineers to hesitate on the brink of a wider application of roller bearings in railway work in this country. Some useful statistics are now available, however, based on experience with these bearings in electric traction work.

It was the hot box problem which caused the Metropolitan Railway to begin experiments with roller bearings in 1930. Five trains were put into service equipped with three different makes of roller bearings in order that actual performance could be studied. Hot boxes were definitely eliminated, and, in addition, savings of from 8 to 15 per cent. in current consumption were effected, besides considerable economies in lubrication and maintenance. The savings in current consumption can be understood, in view of the claim that starting resistance was reduced to such an extent that trains once brought to a standstill tended to move again under their own weight in stations where there was a slight incline.

Although roller bearings are more expensive than plain, the Metropolitan Railway found that the increased reliability fully justified the extra expense. Subsequently, a further 65 coaches were put in service and these were equipped with tapered roller bearings for all axleboxes. This section of the London Passenger Transport Board now has more than 100 coaches in service fitted with roller bearings, 97 being of the Timken tapered type. It is estimated that more than 15,000,000 coach miles of service have been given without a single bearing failure.

Exhaustive tests were carried out on the coaches equipped with roller bearing axleboxes and apart from the power savings gave the following results:—

Saving in cost of lubricant	76 per cent.
Saving in labour cost of lubricating	61 per cent.
Reduction in starting friction from 17·6 to 7·6 lb. per ton	

From these results it has been estimated that, allowing a life of seven years only for the bearings, there would be an ultimate return of 10 per cent. on the extra capital expenditure. But during a life of seven years, the mileage covered would be in the region of 420,000 miles whereas tapered roller bearings on some railway systems have already run over 1,000,000 miles and are still in service. 10 per cent. is, therefore, a conservative estimate of the return likely to accrue on the extra capital invested in roller bearing equipment working under such conditions. The actual return cannot be stated until the life of roller bearings is determined by a use-till-destruction experiment on some railway. At present, the condition of those bearings which have run more than 1,000,000 miles indicates that considerable further life can be expected.

Although the question of first cost is of considerable importance, and quite apart from the return which can be expected, the fact that roller bearings do eliminate hot boxes is in itself a factor demanding more than passing interest. The problem of how to avoid hot boxes assumes very great importance on intensive electric railway services. On such a line as the Inner Circle where an extremely heavy load has to be allowed for at all times, and where frequent service must be maintained, particularly during the rush hours, the occurrence of a single hot box can completely disorganise the traffic. It is on such services where short runs between stations necessitate frequent stops that bearings are subjected to the most rigorous conditions. With plain bearings, high starting resistance leads to heavy power consumption, and in addition the bearings and journal are subjected to considerable wear due to the lack of oil film at the moment of starting.

Taking the experience of the Metropolitan Railway with its roller bearing equipped electric stock, and also having in mind results on other railways, it may be stated that, in a general way, extra initial cost is justified by the following advantages of roller bearings.

(1) Complete freedom from hot boxes.
(2) Greater availability of rolling stock over long periods of service without overhaul.
(3) Reduction in the cost of inspection and maintenance.
(4) Longer axle life due to absence of wear and alternate heating and cooling.
(5) No necessity for reducing the size of trains during cold weather. (This of course applies only in countries with extremely low temperatures.)
(6) Reduction of starting and running friction.
(7) Heavier trains for same power consumption or reduction in power consumption for same size of train.
(8) Increased comfort for passengers.

Mercury Vapour Frequency Converter

The German State Railway has recently ordered from the A.E.G. a grid-controlled mercury vapour frequency converter of 3,600 kVA normal output, to be used in converting 45,000-volt 50-cycle three-phase supply to 15,000 volt, $16\frac{2}{3}$-cycle single-phase current for the operation of the Wiesentalbahn, Baden, which runs from Basle to Zell and Sackingen. The importance of this development from the standpoint of main line traction supply lies in the possibility which it offers of serving a single-phase electrification scheme from the general three-phase supply network through static substations of relatively low cost and high efficiency. The new plant will be installed in the Basle substation, fed from the Rheinfelden transformer station, and will replace converting machinery and buffer battery equipment which has been in service since 1913. From the results of tests in the makers' works, it is expected that substantial reductions will be effected in overall running costs.

The heavy fluctuations of load on the relatively short Wiesental line (about 50 km. or 31 miles in length) offer an opportunity of testing the frequency-converter under difficult conditions of service. The specification calls for a single-phase output of 3,600 kVA. continuously, 4,000 kVA. for 30 min., and 6,000 kVA. for 1 min.; an efficiency of 90 per cent. at full load (3,600 kVA.) with single-phase power factor 0·7, and 91 per cent. at half-load; and a three-phase power factor of 0·6 when the single-phase power factor is 0·7. No provision is made for power factor improvement, the line voltage drop being insufficient to justify the cost of corrective equipment. At a load factor of 30 per cent., the annual efficiency of the new converter will be about 83 per cent., compared with 70 per cent., for rotary converter equipment, and 66 per cent. for the existing plant. The freedom from harmonics in the single-phase voltage is such that no smoothing device is required, and the vapour converter can operate satisfactorily in parallel with rotary converters of sinusoidal wave form. On the other hand, there are pronounced harmonics in the current taken from the three-phase supply, but tests indicate that the effect of these on the voltage wave form of the three-phase system will be negligible, the peak load current of the converter (about 50 amp.) being very small compared with the capacity of the Rheinfelden and associated power stations and transmission lines. The large-scale tests on the development apparatus appear to have established the satisfactory operating characteristics of the mercury vapour frequency converter, and the Basle installation will be in service shortly.